

Title:

Functional threshold power is not equivalent to lactate parameters in trained cyclists

Type: Original Investigation**Authors and affiliations:**

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Running head: FTP has no equivalence to lactate parameters

ABSTRACT

Functional threshold power (FTP) is derived from a maximal self-paced 20-min cycling time-trial whereby average power output is scaled by 95%. However, the physiological basis of the FTP concept is unclear. Therefore, we evaluated the relationship of FTP with a range of laboratory-based blood lactate parameters derived from a sub-maximal threshold test. Twenty competitive male cyclists completed a maximal 20-min time trial and an incremental exercise test to establish a range of blood lactate parameters. FTP (266 ± 42 W) was strongly correlated ($r = 0.88$, $P < 0.001$) with the power output associated with a fixed blood lactate concentration $4.0 \text{ mmol}\cdot\text{L}^{-1}$ (LT_{4.0}) (268 ± 30 W) and not significantly different ($P > 0.05$). Whilst mean bias was 2.9 ± 24.6 W, there were large limits of agreement between FTP and LT_{4.0} (51 to -45 W). All other lactate parameters, lactate threshold (LT) (236 ± 32 W), individual anaerobic threshold (IAT) (244 ± 33 W) and LT thresholds determined using the Dmax method (221 ± 25 W) and modified Dmax method (238 ± 32 W), were significantly different from FTP ($P < 0.05$). Whilst FTP strongly correlated with LT_{4.0}, the large limits of agreement refutes any equivalence as a measure with physiological basis. Therefore, we would encourage athletes and coaches to use alternative field-based methods to predict cycling performance.

Keywords

Cycling; performance; lactate; profiling; time trial; endurance

59 **Abbreviations**

60 FTP, Functional threshold power; LT, lactate threshold; (Dmax) LT, lactate threshold
61 assessed using the Dmax method; (mDmax) LT, modified version of the Dmax method;
62 LT_{4.0}, the workload according a fixed blood lactate concentration 4.0 mmol·L⁻¹; IAT,
63 individual lactate threshold; B[La], blood lactate.

INTRODUCTION

Endurance capacity can be regarded as the highest steady-state exercise that is predominantly supported by oxidative energy pathways (10) which is typically assessed during a graded exercise test, in conjunction with blood lactate (B[La]) profiling. In combination with other tests, B[La] thresholds can provide an indication of endurance capacity, as well as establishing an athlete's fractional utilisation (10). There is considerable variation in the methods used to detect blood lactate thresholds (LT). Traditionally, LT has been determined by plotting B[La] versus workload and reporting the point of intersection between two linear splines (22). However, due to the often reported curvilinear properties of the B[La] curve this approach has drawn criticism. Dmax (9) and modified Dmax (mDmax) (4) methods were developed to overcome these disadvantages by plotting points on the B[La] curve and extracting perpendicular values from this line. However, they depend on both the initial and final B[La] lactate readings. The individual lactate threshold (IAT), based on a 1.5 mmol·L⁻¹ increase above the minimum lactate equivalent (13), has been shown to correlate with maximal lactate steady state (MLSS), conceptually recognised as the upper border of constant load exercise that occurs without a continuous rise in B[La] (14). Meanwhile, fixed B[La] thresholds ranging from 1-4 mmol·L⁻¹ (14) have been reported, with the workload according the fixed blood lactate concentration 4.0 mmol·L⁻¹ (LT_{4.0}) (16), otherwise referred to as the onset of blood lactate accumulation (OBLA), being the most frequently described. Indeed, LT_{4.0} has been suggested to be the highest B[La] that is sustainable for a longer duration and has also shown good correlation MLSS (16). However, such fixed markers do not account for inter-individual variation in endurance capacity (14). Despite the range of approaches, LT thresholds are of considerable

importance and are routinely used to demarcate the domains of exercise intensity, which inform the prescription of training intensities or help to predict performance (8).

While physiological laboratory tests can determine a range of LT parameters to provide reliable and meaningful information for a cyclist, they can be invasive, expensive and require specialist knowledge or facilities. As such, field-based tests to quantify the maximum endurance capacity of cyclists might provide a preferable alternative and can be conducted using commercially-available portable power meters. Non-invasive assessments, requiring only mechanical data from one's own equipment, therefore provide attractive surrogate testing options. Endurance performance is typically assessed by determining the highest average power output achieved over 1 hour (1-h), which strongly correlates with road racing performance (3,11). However, given the demands of a 1-h self-paced exercise test, alternative tests have gained popularity among competitive and recreational cyclists for the prescription of training intensities, and monitoring adaptations to training. One such alternative is the functional threshold power (FTP) test. This test involves a maximal self-paced 20-min cycling time-trial, whereby average power output is scaled by 95% (1). Conceptually, it defines the highest average power output that can be sustained over 1-h, without fatigue, ostensibly reflecting the maximum aerobic potential before an exponential rise in B[La] (1,2).

A series of recent papers have examined FTP, independently reporting agreement between a range of physiological parameters, such as: the individual anaerobic threshold

(IAT) (6), lactate threshold (assessed using the (Dmax) method) (Dmax) LT (33), lactate-turn-point (26), MLSS (7), critical power (24), maximal oxygen consumption ($\dot{V}O_{2max}$) (12), as well as reporting a strong relationship with 60-min power output when expressed at 90% of a 20-min time-trial (TT) (23). A number of other studies have also examined FTP utilizing shorter maximal self-paced 8-min TTs, reporting agreement with LT_{4.0} (15), the power output associated with +1 mmol·L⁻¹ above baseline (21), and (Dmax) LT (30). However, there does not appear to be agreement in the literature regarding the physiological basis of FTP. Indeed, no single study has examined a range of B[La] parameters in one experimental design to identify a physiological analogue to FTP. Therefore, the purpose of this study was to evaluate the relationship of FTP with a range of B[La] parameters, derived from a sub-maximal threshold test, in well-trained cyclists.

METHODS

Experimental approach to the problem

Participants completed two separate testing sessions separated by at least 72-h. Firstly, a maximal 20-min time-trial and secondly, an incremental exercise test to establish blood lactate parameters, followed by a ramp test to exhaustion for the purpose of establishing $\dot{V}O_{2\max}$. Data was collected consistently using a portable power meter appended to a laboratory bicycle.

Participants

Twenty well-trained, competitive male cyclists (mean \pm SD; age 36 ± 9 years, stature 180 ± 5 cm; body mass 76 ± 8 kg; $\dot{V}O_{2\max}$ 60.4 ± 7.1 mL \cdot kg $^{-1}\cdot$ min $^{-1}$) volunteered to participate in this study. All cyclists were active in regional/national racing time trials, road races or triathlons and were familiar with FTP testing. Participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. All procedures conformed to standards set by the *Declaration of Helsinki*. The participants were asked to refrain from strenuous exercise for 48-h before each test, as well as alcohol and caffeine 24-h before testing, and to consume 0.5 L of water 2-h prior to arrival.

FTP test

The FTP test was conducted following a warm-up at 100 W for 10-min. Participants were asked to complete 2 x 20-s maximal efforts above their anticipated FTP intensity before

146 resting for 5-min. Tests were conducted in a performance laboratory, on a laboratory
147 bicycle fitted with a portable left crank-based power meter (STAGES, Stages Cycling,
148 Boulder, CO, USA), and fixed to an electronically-braked indoor trainer (Computrainer,
149 RacerMate One, Racermate, Seattle, USA). Prior to each trial, the recommended zero off-
150 set calibration was performed for the STAGES power meter according to the
151 manufacturer's instructions, and the Computrainer was calibrated according to the
152 manufacturer's instructions. Ambient temperature (17 ± 1 °C) and relative humidity ($33 \pm$
153 8 %) were controlled and fan cooling was provided during all tests positioned in front of
154 the cyclist at an angle of 45 degrees. Fan speed was set to an air speed of 10.4 km/h
155 (HVD24, Sealey Power Products, Bury St Edmunds, UK). Participants were allowed to
156 change gear to increase resistance during the FTP test and cadence was freely chosen
157 dependant on their preferred pacing strategy. Participants were instructed to pace their
158 efforts to achieve the highest average power output across the 20-min effort. B[La] was
159 collected 1-min pre and 1-min post-test. Participants were also asked to report their
160 rating of perceived exertion (RPE) (5) at the end of the 20-min test. Non-specific verbal
161 encouragement was given at irregular intervals. Power output and heart rate data were
162 recorded but concealed from the participant. Heart rate was recorded continuously
163 throughout all trials by a Garmin heart rate monitor (HRM3-SS, Garmin (Europe) Ltd.,
164 Southampton, UK) that wirelessly transmitted to the Garmin headunit (Garmin Edge 510
165 GPS headunit, Garmin (Europe) Ltd., Southampton, UK). During the FTP test, a
166 countdown clock from 20-min was the only visible external cue on the headunit. FTP

was calculated from data collected during the 20-min TT using the following equation:

20-min mean power output x 0.95 (1).

$\dot{V}O_{2max}$ and blood lactate test protocols

The incremental test was programmed by the indoor cycle trainer software (RacerMate One, Racermate, Seattle, USA), starting at 120 W and increasing by 30 W every 4-min to evaluate B[La] accumulation relative to exercise intensity. The submaximal test was terminated at the end of the stage that produced a B[La] above 4 mmol·L⁻¹. Participants then rested for 10-min before beginning a ramp test, starting at 150 W and increasing by 1 W every 2-s (30 W·min⁻¹), until volitional exhaustion. Breath-by-breath expired gases were recorded to assess $\dot{V}O_2$ (Oxycon Pro, Erich Jaeger GmbH, Hoechberg, Germany). Blood samples were collected from the earlobe via capillary puncture and analysed using an automated B[La] analyzer (Biosen C-Line, EKF Diagnostics, Cardiff, UK) in the last 30-s of each stage, along with RPE.

Blood lactate parameters

B[La] concentration (mmol·L⁻¹) during the incremental ramp test was plotted against power output. A validated online software program, Lactate-E, was used to determine the power output associated with B[La] parameters 1-4 as below (25). Five common methods were used to determine B[La] markers: i) Traditional LT, as the point of intersection between the two linear splines (22); ii) (Dmax) LT, the point that yields the maximal distance from the B[La] curve as a function of workload to the line formed by the two end

points of the curve (9); **iii) (mDmax) LT**, the point that yields the maximal distance to the straight line formed by the LT and value at cessation of exercise (4); **iv)** the workload according a fixed blood lactate concentration $4.0 \text{ mmol}\cdot\text{L}^{-1}$ (**LT_{4.0}**) (16); **v)** Individual lactate threshold (IAT) was defined at a **B[La]** concentration $1.5 \text{ mmol}\cdot\text{L}^{-1}$ above the minimum ratio between **B[La]** and work rate (13).

Data Analysis

A Pearson product-moment correlation was computed to evaluate the relationship between the FTP performance variable and **B[La] parameters**. A one-way analysis of variance (ANOVA) with repeated measures was used to compare LT, LT_{4.0}, **(Dmax) LT**, **(mDmax) LT** and IAT with FTP. If sphericity was violated, a Greenhouse-Geisser correction was applied. Pair-wise comparisons were made with a Bonferroni adjustment. Limits of agreement (LOA) were established to assess the bias (mean difference) and random error (1.96 SD of the difference) between PO at FTP and measures of B[La]. Typical error was calculated by dividing the standard deviation of the difference score **by the square root of 2**. A paired sample *t*-test investigated differences (bias) between FTP and B[La]. All statistical analyses were performed using SPSS (IBM SPSS statistics 22 Inc, USA). Data are presented as mean \pm SD ($n = 20$). Significance was set at $P < 0.05$.

RESULTS

Mean power output during the 20-min TT was 280 ± 45 W, which corresponded to a calculated FTP of 266 ± 42 W (95% CI [246, 285]) (Figure 1). A one-way ANOVA with repeated measures indicated significant differences between parameters ($F_{(2.002, 38.035)} = 40.493$, $P < 0.001$, $\eta_p^2 = 0.681$). Post hoc tests using the Bonferroni correction revealed that power output at LT_{4.0} (268 ± 30 W, 95% CI [255, 283]) was not different from the power output at FTP ($P = 1.000$). However, power output at LT (236 ± 32 W, 95% CI [221, 251]) ($P = 0.002$), (Dmax) LT (221 ± 25 W, 95% CI [209, 232]) ($P < 0.001$), (mDmax) LT (238 ± 32 W, 95% CI [223, 252]) ($P = 0.008$), and IAT (244 ± 33 W, 95% CI [228, 260]) ($P = 0.023$) were significantly different (Figure 1).

*** Insert figure 1 here ***

Of the five lactate parameters calculated, power output at LT_{4.0} was most strongly correlated with FTP ($r = 0.88$, $P < 0.001$) (Figure 2), with a mean bias of 2.9 ± 24.6 W (95% LOA 48.2 W). All other lactate parameters were correlated: LT ($r = 0.79$, $P < 0.001$), (Dmax) LT ($r = 0.80$, $P < 0.001$), (mDmax) LT ($r = 0.75$, $P < 0.001$) and IAT ($r = 0.85$, $P < 0.001$) (Figure 2). Mean bias and absolute limits of agreement are shown in Table 1.

*** Insert figure 2 here ***

*** Insert Table 1 here ***

229 No correlation was found between cardiovascular fitness ($\dot{V}O_{2\max}$) and the ability to
230 replicate a 20 min TT with respect to the mean difference between FTP and LT_{4.0} ($r =$
231 0.353, $P < 0.05$) (Figure 3).

232 *** Insert figure 3 here ***

DISCUSSION

We investigated FTP, derived from a maximal 20-min TT, and its association with several established laboratory-based B[La] measurements. Power output associated with FTP was not different from the power output at LT_{4.0}, and was strongly correlated. However, there were differences between FTP and LT, (Dmax) LT, (mDmax) LT and IAT. Whilst there was no mean bias between FTP and LT_{4.0} (~ 3 W), a large random error in the inter-individual data (~ 100 W) questions their equivalence. Therefore, we suggest that FTP does not have an equivalent physiological basis to any of the tests used herein and, therefore, cannot be used interchangeably.

FTP is defined as the highest average power output that can be sustained over 1-h without fatigue (1). Hence, it is purported to reflect the maximum aerobic potential before lactate accumulation rises exponentially. A number of recent papers have examined the physiological basis of FTP (6,7,12,24,26,33), however there has been no attempt to examine the best correlate across a range of lactate parameters. More than 25 methods have been proposed to calculate lactate threshold concepts (14,18). Here, we examined five established B[La] parameters and report that FTP closely approximated LT_{4.0} with mean power across all athletes tested agreeing within 1% of the power output at LT_{4.0}. Crucially, we report this relationship in the context of a range of other established B[La] parameters. The power output associated with LT_{4.0} has been suggested to be a good indicator of MLSS (16), and is strongly correlated with professional cycling

performance (28). However, during constant load exercise tests at the power output associated with $LT_{4.0}$, continual rises in $B[La]$ ($> 8 \text{ mmol}\cdot\text{L}^{-1}$) have been described (32) suggesting this may not approximate a steady state exercise capacity (27). This lack of agreement with a fixed measure of $B[La]$ has been explained by inter-individual differences, which may underestimate anaerobically trained athletes or overestimate aerobically trained athletes (14,32). Therefore the basis of a fixed $B[La]$ parameter reflecting an individual's relationship with a field-based measure to quantify endurance capacity is unclear. Whilst it has been argued that individualised LT parameters better represent physiological capacity, we found significant differences between these measures and FTP. Lactate parameters such as IAT (13), have been shown to elicit a steady state $B[La]$ of $4.0 \text{ mmol}\cdot\text{L}^{-1}$ when cycling at the equivalent power output for 50 min (31). (mDmax) LT has been suggested to best predict cycling performance (17), and strongly corresponds to 1-hr performance in well-trained female cyclists (4). Together, these lactate parameters represent valid indicators of endurance performance and yet demonstrate no equivalence with FTP.

Despite the apparent close agreement in mean power between FTP and $LT_{4.0}$ ($\sim 3 \text{ W}$), a large random error (+ 19.2 to - 17.0 %; $\sim 100 \text{ W}$) was reported. Such dispersion in the data would therefore refute equivalence between these measures, and further question the ability of FTP to even predict $LT_{4.0}$. The inter-individual variance in the association between these measures, across the twenty well-trained competitive cyclists recruited in this study, highlights the potential negative implications for using FTP to demarcate the

domains of exercise intensity for training prescription. Alternate methods have been reported to determine the highest sustainable exercise intensity in the laboratory, which include modelling of the power-duration relationship to derive a measure of critical power (CP) (19,29). In a recent study, CP was determined by a series of 4-5 self-paced maximal TTs to obtain a range of times between ~2 and 15 min showing good agreement between CP and FTP (mean bias of -3 W) (24). However, Morgan and colleagues, in parallel to our own observations, reported a large random error (+ 10.9 to - 13.1 %) again refuting any equivalence between these measures (24). High agreement has been reported between field-based (outdoor velodrome) and lab-based estimates of CP (20), making this a useful alternate tool for coaches and athletes. To establish whether training status may have affected the participant's ability to reliably perform a maximal 20 min TT in line with their physiological capacity, we examined the relationship between $\dot{V}O_{2max}$ and the mean difference between FTP and LT_{4.0}. However, there was no relationship ($r = 0.353$) between these measures, suggesting that aerobic capacity does not explain the large inter-individual variation in agreement between FTP and LT_{4.0}. Therefore, we recommend that athletes and coaches should reconsider the appropriateness of FTP as a field based test used to prescribe training zones. Given the lack of agreement between FTP and the laboratory-based physiological measures herein, the physiological basis of the FTP is questionable.

PRACTICAL APPLICATIONS

298 Based on the data provided, FTP cannot be considered as a field-based alternative to the
299 gold-standard laboratory derived physiological measures. Therefore, training intensity
300 prescription should not be solely based on data derived from FTP testing. We would
301 encourage athletes and coaches use alternative field-based methods to predict cycling
302 performance. We recommend that laboratory-based assessments of B[La] parameters are
303 used for the determination of LT and MLSS, or that athletes are assessed using the power-
304 duration relationship, to derive a measure of CP.

305

306

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309 The STAGES portable crank-based power meter used in this study across all testing was

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311 study do not constitute endorsement of the product by the authors or the journal.

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403
404

FIGURE LEGENDS

Figure 1. Mean and individual differences in power output estimated during a 20-min TT FTP test and a range of blood lactate parameters determined during laboratory incremental cycling test ($n = 20$). All data are presented individually and as mean \pm SD. * indicates significant difference from FTP. Abbreviations: lactate threshold (LT); lactate threshold assessed using the Dmax method ((Dmax) LT); modified version of the Dmax method ((mDmax) LT); the workload according a fixed blood lactate concentration 4.0 mmol·L⁻¹ (LT_{4.0}); and individual lactate threshold (IAT).

Figure 2. The relationship between 20-min TT FTP power output and (A) the workload according a fixed blood lactate concentration 4.0 mmol·L⁻¹ (LT_{4.0}), (B) lactate threshold (LT), (C) lactate threshold assessed using the Dmax method ((Dmax) LT), (D) modified version of the Dmax method ((mDmax) LT), (E) individual lactate threshold (IAT), determined during a laboratory incremental cycling test ($n = 20$). The dashed line represents the line of identity and solid line is the regression.

Figure 3. The relationship between $\dot{V}O_{2\max}$ and the mean difference between LT_{4.0} and FTP ($n = 20$).

Table 1. Mean bias and absolute limits of agreement for lactate parameters compared to FTP presented as power output (W).

	Mean			Lower	Upper	Typical
	bias	SD	95% LOA	limits	limits	error
LT _{4.0}	2.9	24.6	48.2	72.7	-23.6	17.4
LT	-30.0	27.5	53.8	81.3	-26.4	19.4
(Dmax) LT	-45.3	27.0	52.9	79.8	-25.9	19.1
(mDmax) LT	-28.2	30.4	59.5	89.9	-29.2	21.5
IAT	-22.0	26.4	51.7	78.1	-25.3	18.7

Abbreviations: lactate threshold (LT); lactate threshold assessed using the Dmax method ((Dmax) LT); modified version of the Dmax method ((mDmax) LT); the workload according a fixed blood lactate concentration 4.0 mmol·L⁻¹ (LT_{4.0}); and individual lactate threshold (IAT); limits of agreement (LOA).

Figure 1.

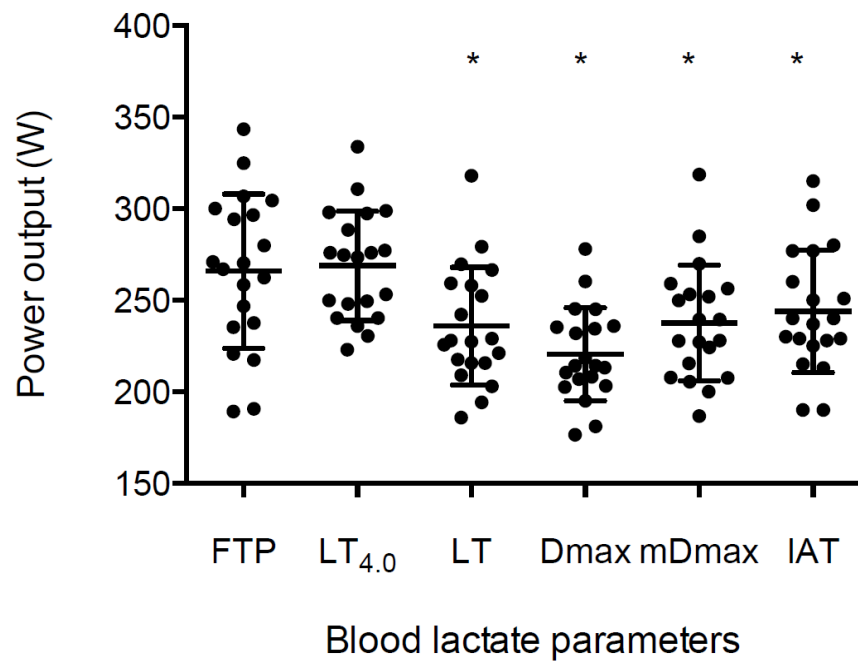


Figure 2.

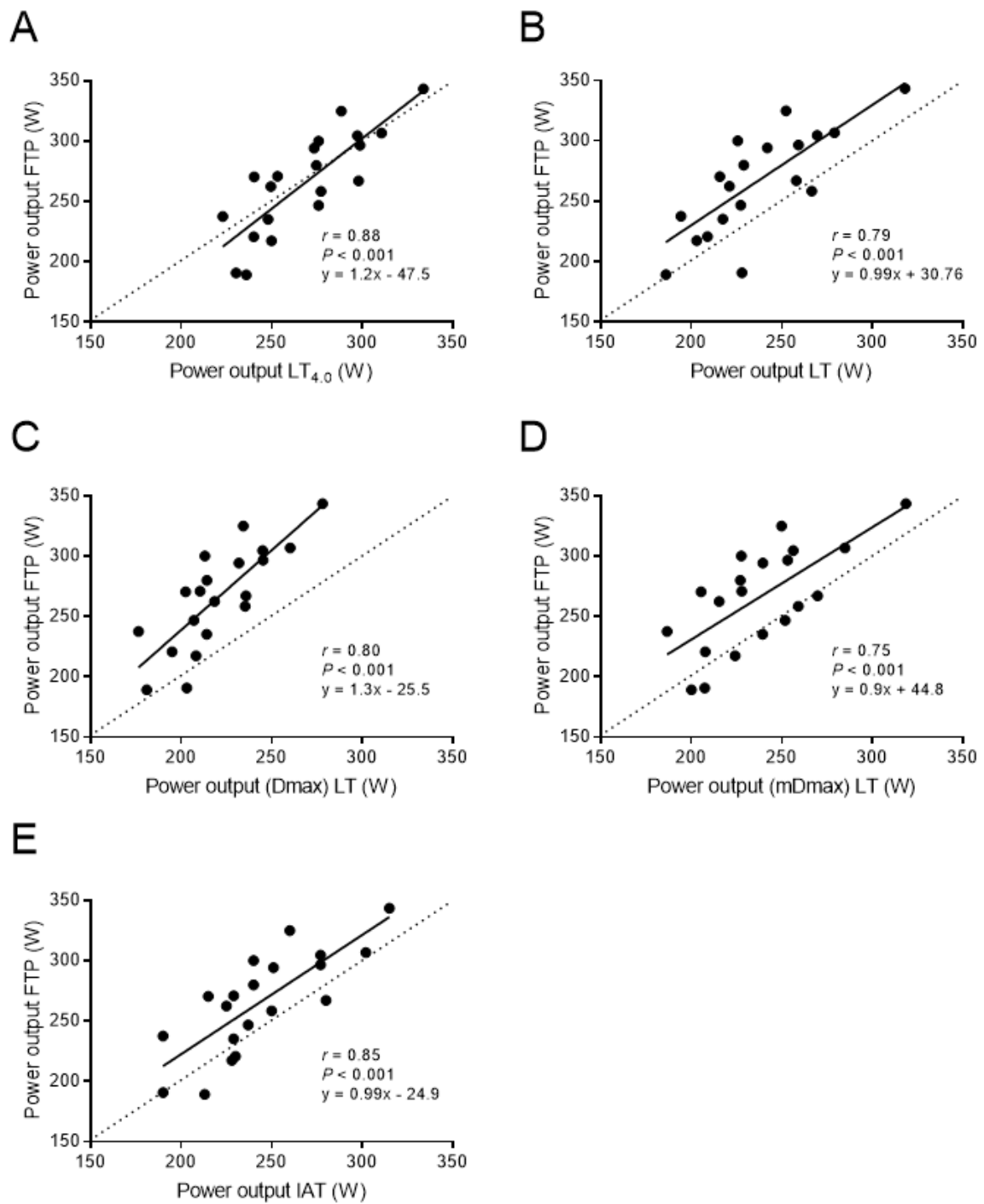


Figure 3.

